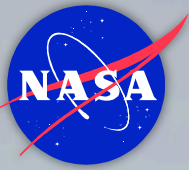# Lessons Learned: Science & Exploration Activities in Remote Field Locations

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Agenda

- Field Research

- Communications Challenges

- Communications Solutions

- Lessons Learned

- Further Research

- Conclusions

Field Research

- Conducting controlled experiments or observing natural phenomena in a remote location of interest

- Allows use of a "real" environment as the laboratory
  - More realistic conditions = more useful data
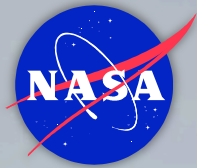 - Good for lunar/planetary analog experiments
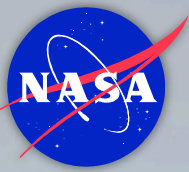
Why Field Work Is Useful

- Provides basic validation of candidate technologies and procedures under mission-like conditions
- Allows evaluation of the usefulness of communications technologies in support of science objectives
- Uncovers operational challenges and unexpected occurrences
- Allows side-by-side comparison of new and existing technologies
- Relatively easy to do – many available locations are good space analogs
- Satellite links provide cost effective relaying of science data to distributed teams
- High-fidelity simulations are possible
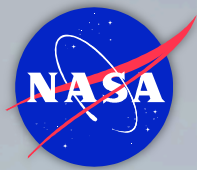
Why Field Work Is Useful to Netwonks

- Networking research
  - High bandwidth, long delay data transfers
  - Multimedia over satellite
  - Evaluation of wireless network technologies for surface exploration activities
  - Ad hoc routing
  - Detailed wireless network monitoring for performance evaluation and security
  - Software defined radio
- Gain experience relevant to NASA space communications efforts
  - Space Communications Architecture Working Group
  - Constellation Program
  - Lunar Communications Working Group

Field Testing Can Help Evaluate...

- New communications standards

- Space-specific modifications

- Mission voice, video and data over wireless

- End-to-end communications – From spacesuit and sensor to space data consumer

- Antenna/hardware design

- Delay tolerant techniques

- Mesh networking technology

- Sensor networks

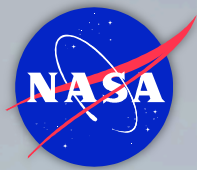- Mission scenarios and operations concepts

Supported Field Experiments

- Science
  - Ground Truthing, Vernal, UT
  - MARTE: Rio Tinto, Spain and Santa Cruz, CA
  - Canadian Arctic – Axel Heiberg Island, Devon Island
- Technology Trials
  - Mobile Agents experiments – Mars Desert Research Station (MDRS), Hanksville, UT
  - Desert RATS, Meteor Crater, AZ
  - K-9 Robot tests, Santa Cruz, CA
  - Ad hoc networking trials, Moss Point, CA, and Meteor Crater, AZ
- Educational Outreach
  - Spaceward Bound, Atacama Desert, Chile
- Disaster Response
  - Post-Katrina emergency communications – NASA Michoud

Mobile Agents – MDRS, Utah

- Testing autonomy and voice recognition software, wireless communications hardware to facilitate human-robotic interaction

Desert RATS – Meteor Crater, Arizona

- Multiple activities, including testing of prototype spacesuits, vehicles, robots, and voice/data communication systems
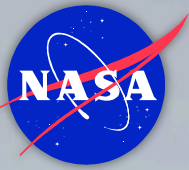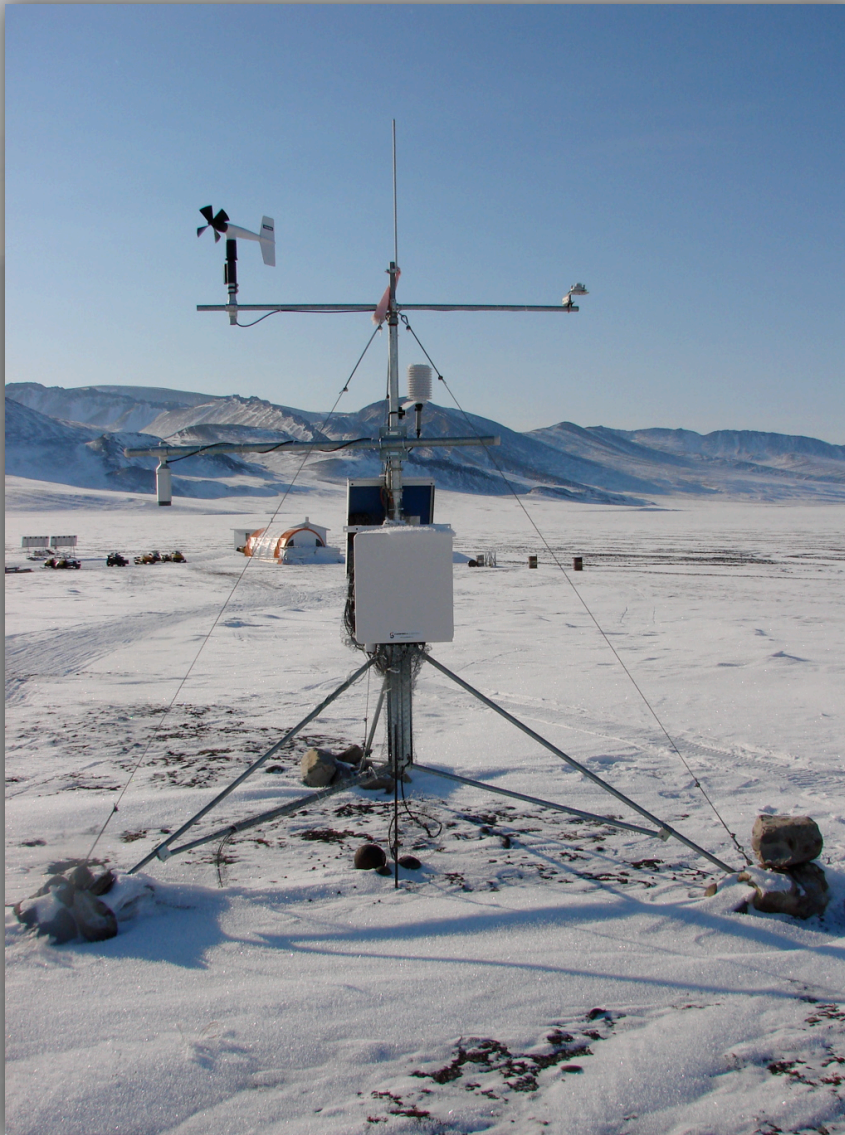
MARTE – Rio Tinto, Spain

- Testing of drill for extracting soil samples for biological, chemical analysis

Axel Heiberg Island, Nunavut, Canada

- McGill Arctic Research Station

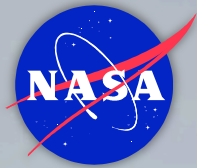- Studies of environment, glaciers, and native flora/fauna
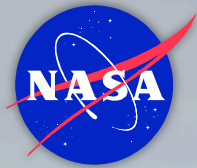
Communications Challenges

- Researchers and equipment must be able to communicate with home institutions…
  - Need connectivity both external and internal to the site
  - Science data
  - Voice/Video
  - Internet usage
- …But no existing communications infrastructure at field site
  - Must bring and set up as part of initial phase of activity
  - Must keep equipment operating in potentially harsh environmental conditions

Application Requirements

- Science data
  - Example: Large data files from science instrument, transferred all at once
  - Key parameters: Low loss rate, high throughput desirable
- Real-time telemetry
  - Example: Continuously streaming sensor data
  - Key parameter: Low latency; low bandwidth often OK
- Real-time video/voice
  - Examples: Skype, VoIP phones
  - Key parameters: Low jitter; high throughput for video
- General Internet usage
  - Examples: E-mail, Web browsing
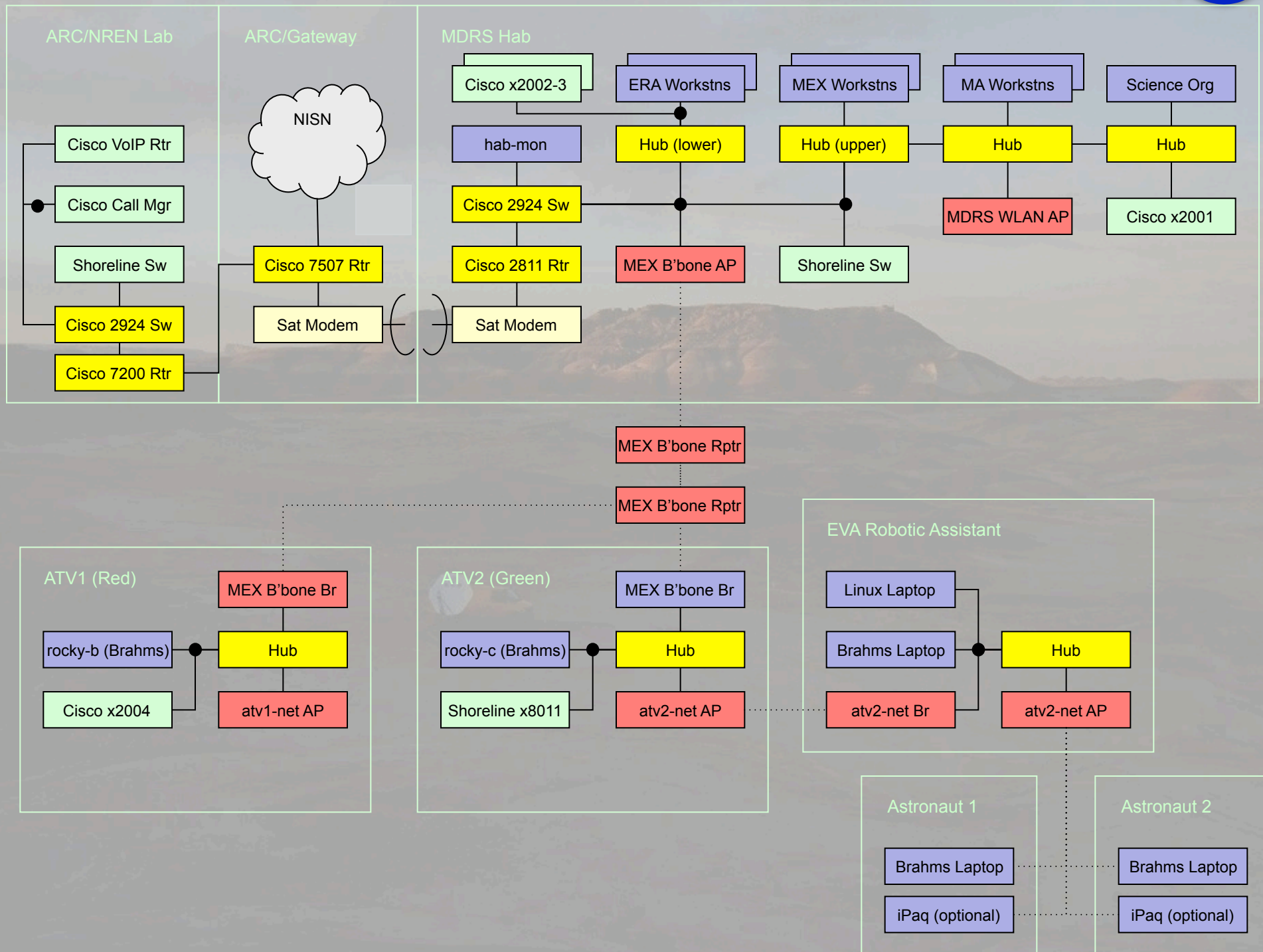 - Key parameters: Low latency, high throughput

Communications Solutions

- Hybrid network
    - On-site wired and wireless LANs
    - Satellite link to network gateway facility
    - Existing terrestrial IP networks
- Design considerations:
    - Specific applications to be used
    - Degree of node mobility
    - Terrain
    - Cost
    - Geographic extent of operations
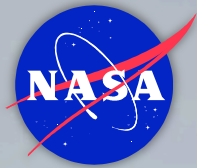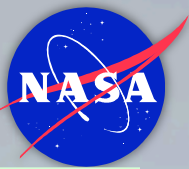
Example Network – Mobile Agents

Architecture Details – On-site

- Transportable satellite ground station
  - Provides satellite connectivity to external networks
  - Dish + transceiver + satellite modem + IP router
- Ethernet-based wired LANs
  - Connect stationary systems (e.g., servers)
- Wireless LANs
  - Connect mobile systems (e.g., laptops, PDAs, science instruments)
  - Based on IEEE 802.11 family (b, a, g, n)
  - Also part of the field research objectives – increased throughput, robustness, and/or range
  - High throughput, low loss at short distances, worse at longer
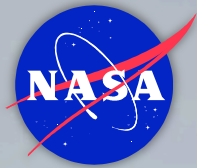- Voice/Video
  - IP phones, video encoders

- Common characteristics
  - Usually K_u band (12-18 GHz), but also C band (4-8 GHz) and K_a band (26-40 GHz)
  - Throughput scales according to price
  - Low loss and jitter
  - High latency (~300 ms one-way)
- Connects to fixed ground station
  - Provides connectivity to one or more terrestrial networks (NASA, academic, commercial)
  - NASA/academic networks have less competing traffic, (sometimes) reduced security concerns
  - High throughput, low loss if no congestion
  - Latency can vary, but jitter is typically low

Example Field Ground Stations
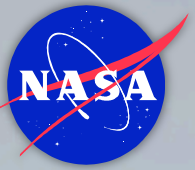
Lessons Learned – System Optimization

- Tuning end systems for high-latency satellite links is essential
  - TCP only sends new packets when previously sent packets are acknowledged
  - In high-latency links, sender can wait a long time for acknowledgement; meanwhile link is idle
  - Can increase TCP window size, or maximum amount of unacknowledged data that sender will tolerate
- Another option: performance-enhancing proxies (PEPs)
  - External devices that intercept TCP traffic and relay over the satellite link using a more suitable protocol
  - Requires no tuning of end hosts, useful for large deployments
  - Additional hardware cost, need ability to insert PEP on both sides of satellite link
  - Preliminary testing – Comparable to TCP tuning on low-speed links; may be better for high-speed links
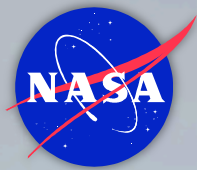
- Multiplexing many types of traffic with different network requirements can cause trouble
  - Some types of traffic may crowd out others
- Can use QoS to prioritize traffic
  - Higher-priority traffic (e.g., science data) is transmitted ahead of lower-priority traffic (e.g., voice/video)
- Monitoring network traffic is important
  - Ensure applications are getting proper service from the network
  - Identify suspicious traffic that may indicate virus activity
- VPN tunneling is helpful
  - Configure system addresses in the lab, then use same addresses in the field – saves setup time

- Wireless channel isolation is a problem for multiple access points/repeaters

- Multipath is a problem in obstruction-laden terrain

- Antenna design and positioning critical

- Ad hoc network protocols can help when RF connectivity is marginal

- Distances up to several miles not a problem with repeaters
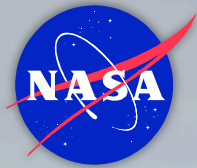
- Sun + snow + K_a band = no link
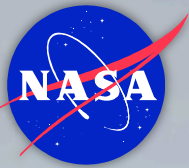
- Communications capabilities enable new mission models
  - Real-time collaboration between researchers in the field and remote colleagues
  - Analysis of collected data by remote supercomputing facilities
  - External reference material (e.g., weather forecasts, data sets for comparison) readily available in the field
- New procedures specifically developed to take advantage of communications capabilities
  - Remote collaborators directing science activities as they occur
  - Distributed planning/analysis of day-by-day activities
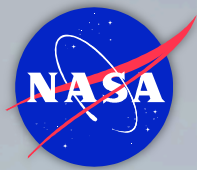
Research Example: Ad Hoc Routing

- Field tested Ames implementation of Dynamic Source Routing
  - Basic Idea: If source *S* and destination *D* are out of range, but there is a path between them through one or more intermediate nodes, then intermediate nodes can relay traffic
- Testing identified conditions in which DSR performed well…
  - Allowed indirect communication where direct RF communication was impossible
- …and also problem areas
  - Route discovery process can be time-consuming, leading to latency spikes
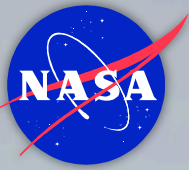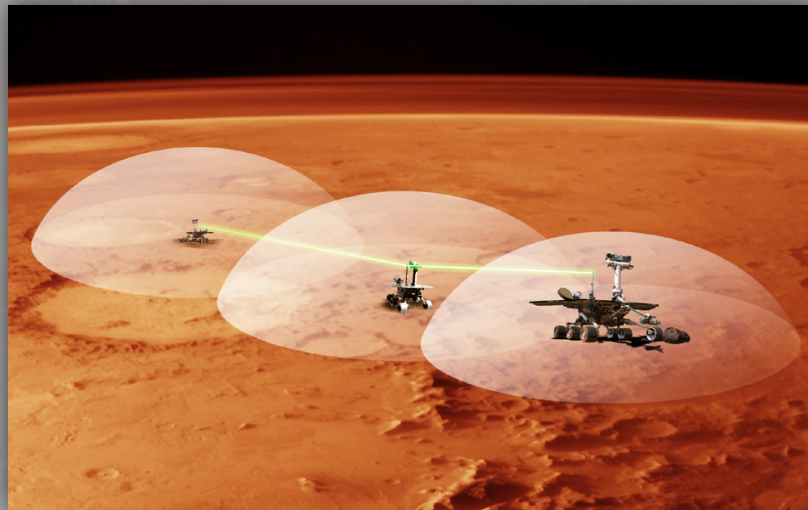
Partnering With Other Organizations

- IP connectivity to commercial VoIP services for Katrina relief

- Local satellite link and RedIRIS for access during Rio Tinto expedition
  - Link supplied by Spanish partner
  - Lower cost for in-country link

- Shared-access commercial satellite service for local pre-deployment field tests
  - Low speed, low cost
  - Tunneled NASA addresses
 - Multimedia not possible

Further Research

- Delay/disruption tolerant networking
  - Store data if suitable connectivity doesn't currently exist

- Mesh networking – IEEE 802.11s
  - Nodes automatically select best neighbor for relaying data, similar to DSR

- Sensor networks
  - Integrating low-power wireless sensors (e.g., ZigBee) into network architecture

- Optimizing voice/video encoding for wireless channels
  - "Less bad" quality over lossy channels, better quality over good channels

- IEEE 802.11n wireless networking standard
  - Higher throughput, better ability to cope with multipath

- IEEE 802.16 (WiMax) wireless networking standard
 - Enable wireless coverage over broader area

Conclusions

- Communications networks provide essential voice, video, and data service to researchers

- Field exploration activities present a variety of communications challenges

- Properly designed network can overcome these challenges and provide critical service
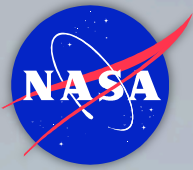
Acknowledgements

- NASA Ames Research Center
  - Intelligent Systems Division
  - Disaster Assistance Recovery Team
  - Space Science and Astrobiology Division
- NASA Glenn Research Center
- NASA Johnson Space Center
- NASA Kennedy Space Center
- McGill University
- Telesat Canada
- Cisco Systems
- ShoreTel, Inc.
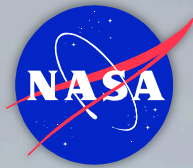
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Questions?